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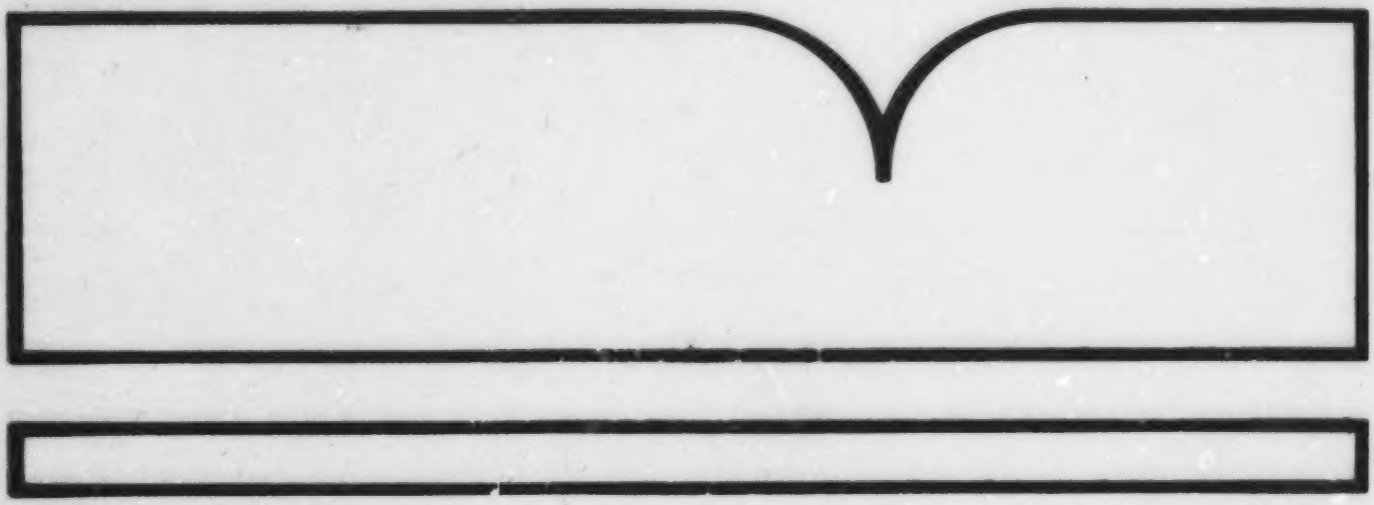
Survey of BAV (Biologische Abfallverwertungs Gesellschaft mbH & Co.) Composting Plants in West Germany

Camp, Dresser and McKee, Inc., Boston, MA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Dec 83



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16. ABSTRACT

An evaluation was made of within-vessel municipal sludge composting systems manufactured by Biologische Abfallverwertungs Gesellschaft mbH & Co. (BAV). In this system, sawdust and recycled compost are mixed with dewatered sludge and inserted into the bioreactor, where the mixture remains for 2 weeks. The compost is then cured in piles for 6 weeks. Eight BAV facilities in West Germany were visited for this study, and meetings were held with BAV representatives. Information was collected on equipment type and integrity, operational procedures and conditions, and the quality and use of the compost. Tests used to evaluate the compost product were also investigated.

The major components of the BAV system include sludge dewatering and storage, sawdust storage, recycled compost handling, materials mixing and bioreactor insertion equipment, the bioreactor, the extraction mechanism for removal of compost from the bioreactor, and the curing piles.

Based on experience with older facilities, BAV has made several significant mechanical modifications to improve the system and to overcome some of the concerns of the earlier reactors. However, they have yet to be tested over time.

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A SURVEY OF BAV COMPOSTING PLANTS IN WEST GERMANY

by
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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This study investigates the performance of BAV within-vessel sewage sludge composting systems in West Germany. These systems are intended to provide composting with superior operational control in a controlled environment. Information presented here will be useful to both consulting engineers and government agencies.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory, Cincinnati

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ABSTRACT

To evaluate the within-vessel sludge composting process of Biologische Abfallverwertungs Gesellschaft mbH & Co. (BAV), eight facilities in West Germany were visited and discussions were held with BAV engineers and researchers. The information collected concerned the type of equipment being used, the integrity of the equipment, operational procedures and conditions, and the quality and use of the compost. Tests that are being used to evaluate the compost product were also investigated.

Mechanical or within-vessel composting occurs in an enclosed container, the bioreactor. These systems are designed to provide operational control superior to that given by conventional or static-pile techniques used for sludge composting. In addition, the composting sludge is isolated from the environment.

In the BAV composting system, sawdust and recycled compost are mixed with dewatered sludge before insertion into the bioreactor. The mixture remains in the reactor for a composting period of two weeks. Following this, the compost is cured in piles for six additional weeks.

The major components of the BAV system include sludge dewatering and storage, sawdust storage, recycled compost handling, materials mixing and bioreactor insertion equipment, the bioreactor, the extraction mechanism for removal of compost from the bioreactor, and the curing piles.

The designs of the components being used at new installations differ from those of the original designs. The equipment has been improved based on experience with older facilities.

One component that has been of major concern is the extractor mechanism. Both its mechanical integrity and operational performance have been questioned. Reports indicate that the mechanism has been subject to breakdowns that require costly and time-consuming repairs. Changes in the system have been made to improve performance, but these have not yet met the test of time. Furthermore, if the sludge added to the reactor is not properly dewatered, the material may cake up and cause system short circuiting.

The compost product has been readily marketable in West Germany. Most of the compost produced at the plants visited is sold.

The compost is normally evaluated by simple observation of odor, color, general appearance, and texture. Observation of the product shows it to be well composted. It has the appearance and texture of a quality topsoil.

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Occasionally, more detailed tests of the compost are made by private consultants. These include tests for plant growth in the product, ratios of humic acids, fluorescence, types of fungi cultures, carbon to nitrogen ratio, ammonia content, and the rate of oxygen uptake. Further evaluations of these tests and the relevance of their results is recommended.

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This report was submitted in fulfillment of Contract No. 68-03-2803 by Camp Dresser & McKee Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from January 16, 1980, to June 26, 1980, and work was completed as of January 23, 1981.

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This document was prepared under the direction of Mr. Paul W. Prendiville, officer-in-charge, and Dr. Albert B. Pincince, project manager. The project engineer was Mr. Robert M. Otoski. The assistance of Mr. John F. Donovan and Ms. Sandra G. Yulke is gratefully acknowledged. Appreciation is also extended to Mr. Indrajit Ganguli, who served as translator for us in West Germany.

The information required for this report was collected with the cooperation and assistance of Mr. Herbert Nemetz, president of Nemetz and Ruess, licensee of the BAV Composting system. Mr. Stephan Schmidt and Mr. Manfred Schneider of BAV also assisted us in our visits to the various facilities. Appreciation is also extended to Dr. Peter Chrometzka of the University of Saarbruecken, West Germany and to Dr. Fritz Balzer of Amonau, West Germany for sharing their findings with us.

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SECTION 1

INTRODUCTION

Within-vessel composting is intended to provide a system with operational control that is superior to that available with conventional windrow or static-pile composting techniques. Additional advantages are that (1) the composting sludge is sheltered from the environment, (2) land requirements are lower than for windrow or static-pile composting, and (3) surrounding areas are protected from odor and other undesirable results of open composting sites.

A report prepared for the U. S. Environmental Protection Agency (EPA) in November 1978 left several questions unanswered regarding the within-vessel composting devices or bioreactors manufactured by Biologische Abfallverwertungs Gesellschaft mbH & Co. (BAV). Battelle-Columbus Laboratories, in association with Battelle-Geneva and Battelle-Frankfurt Laboratories, had evaluated within-vessel sewage sludge composting systems in Europe. The evaluation included a literature review, discussions with composting process inventors, license holders, plant manufacturers and plant operators, and site visits to several plants. In addition, a 3-month on-site investigation was conducted of a BAV composting reactor at the Hochheim wastewater treatment plant.

Battelle-Columbus identified several problems at Hochheim. The bioreactor's extractor mechanism had failed four times since plant startup. Each time, repair required that the bioreactor be emptied manually. According to Battelle, another major problem was the quality of the product from the bioreactor; while they were studying the Hochheim plant, the sludge was poorly composted. Battelle suggested that the poor performance was caused by short-circuiting. They had observed that sticky sludge tended to cling to the walls of the bioreactor. This would have resulted in a reduced effective volume and inadequate composting. BAV claimed that the source of these problems was the plant's centrifuge and not the bioreactor. They claimed that the sludge being added to the bioreactor was too wet.

After reviewing the Battelle-Columbus draft report, EPA decided that because of the short duration of the on-site study and the mechanical breakdowns during the study, that the conclusions reached in the report might not be representative of the BAV process. Furthermore, BAV representatives indicated that during the last two years, several new BAV compost reactors with improved mechanical systems were put into operation. For these reasons, EPA contracted with Camp Dresser & McKee Inc. to conduct a new study of the BAV composting device.

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PURPOSE AND METHOD OF STUDY

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This study had three major objectives:

1. To gather factual information about BAV composting reactors in Germany and to present this information so that it may be used by consulting engineers, EPA, and other local and state agencies in their decision making;

2. To use the information collected to decide on the necessity of a detailed onsite investigation; and,

3. To recommend the location and nature of any detailed investigation undertaken.

To fulfill these charges, we visited eight BAV facilities, met with BAV engineers, and visited two West German researchers.

The visits to the eight plants took place over about 4 working days. The time spent at the first plants visited was generally greater than that spent at the others, since the equipment at the various plants was found to be quite similar.

Originally, we anticipated visits to all BAV plants in Germany, but the similarities in equipment from plant to plant made it unnecessary. Instead, we visited facilities that represented various periods in the evolution of the BAV design. By doing this, we were able to trace the development of the equipment components. These onsite reviews, plus the discussions with BAV engineers and with the researchers, were adequate to allow a fair evaluation of the process.

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SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. The BAV composting system appears to provide a well-composted product. This is true if the sludge dewatering is adequate, the system is operated as designed, and the material from the composting vessel is cured for approximately six weeks. Though the compost product extracted from the BAV reactor has the feel and texture of a quality topsoil, analyses show that the composting of this material is incomplete, and that the curing period is required for product finishing.

Like the compost taken directly from the reactor, the cured product is aesthetically pleasing with respect to color, odor, and general appearance. In addition, however, laboratory tests show it to be mature.

2. A potential for short-circuiting exists. Apparently, it is possible for sludge materials to short-circuit through the reactor, so that not all the material has the desired detention. Nevertheless, this potential problem was not evident at the eight facilities visited.

3. The BAV composting reactor system has undergone significant developmental changes. This evolution has not been one of the total system. Rather it has occurred component by component. If a component required frequent maintenance or premature replacement, its design and performance were evaluated. Such an evaluation has typically resulted in a design modification.

4. Detention time and temperature are the contolling process parameters. BAV has selected a detention time of 14 days as the main process operation criteria. Probes are provided to continuously monitor temperature within the reactor. Temperature is reported to reach over 60°C for 4 days, but documentation at most plants is poor. Temperature is modified by adjusting airflow. Relationships between airflow and temperature have not been developed.

5. The compost product has been successfully marketed. Most of the compost product produced is sold, either in bags or in bulk lots. The product is used in improving poor soils, farming, in private gardening, and on lawns.

6. Tests have been developed to evaluate the quality of compost. No standardized tests are available to test for the quality of compost. Investigators of the BAV product test it using plant growth, ratios of humic acids,

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fluorescence, types of fungi cultures, carbon to nitrogen ratios, ammonia contents, the rates of oxygen uptake, and other tests they have devised.

RECOMMENDATIONS

As noted, the original intent of our work was to visit all BAV installations in Germany to obtain information concerning the reactor and to determine the need for a detailed onsite investigation of a selected facility. We believe that the information presented in this report is sufficient to obviate additional site visits, except perhaps, to answer new questions that might be raised.

The detailed onsite investigations were to be used to determine whether the process worked as intended. Since we have concluded that the process produces a suitable compost product, we find that this extended study is not necessary. Furthermore, BAV has not expressed a strong desire to continue marketing the present within-vessel composting model to the United States. A new type of reactor, the "tunnel reactor" (see Appendix A) is being developed by BAV. Furthermore, Battelle-Frankfurt may soon conduct a follow-up study of the BAV reactor.

Investigations of techniques to measure the maturity of compost should be undertaken. A number of tests presently used to study BAV compost maturity are outlined in this report. Study of these tests is required to determine the relevance of the results and to better define the procedure and criteria for interpretation of the measurements taken. Similar study of the rate at which composting occurs, both in the reactor and in the curing piles, is also recommended.

Although BAV has made several significant mechanical process modifications to improve the system, they have yet to withstand the test of time. Some follow-up assessment of these changes should therefore be made.

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SECTION 3

THE BAV SYSTEM FOR WITHIN-VESSEL COMPOSTING

OVERVIEW OF THE PROCESS

Figure 1 is a flow diagram of a BAV composting installation. Sludge cake is first mixed with sawdust and recycled compost product. The sawdust and recycle absorb moisture and give the mixture a texture that aids air passage and distribution. The sawdust is also a source of carbon for the composting process.

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The mixture is then conveyed to a silo which is called the "bioreactor." It is in this bioreactor, within a typical detention time of fourteen days, that the composting takes place. When removed from the bioreactor, the compost produced is either recycled or is sent to a curing pile, where it is cured for at least six weeks prior to removal from site.

A bioreactor, a cylindrical, silo-like structure, is shown in Figure 2. The volume of a bioreactor typically ranges from 50 to 300 m^3, although reactors as large as 600 m^3 have been built. It is simply a hollow cylinder designed with the intention that sludge pass through, by gravity, in a plug flow mode. At the top, the silo is fitted with a mechanical spreader, to even out the mixture added to the reactor. Located within the reactor are a number of carbon dioxide and temperature monitoring probes for process control. There is an air diffuser system on the reactor bottom, for aeration of the composting mixture. Sludge is removed from the reactor by a drag-flight conveyor mounted on an arm at the bottom of the reactor. The arm pivots at the center of the reactor base and swings around the bottom of the reactor, collecting composted sludge from all over the reactor bottom. This extraction mechanism is shown in Figure 3.

Conveying devices and storage tanks are required for the sawdust, the recycled compost, and for the sludge. The sawdust system consists of a bulk storage area, a day storage bin, and mechanisms for conveying sawdust from bulk storage to day storage and, finally, to the mixing point. Compost for recycle is conveyed from the bioreactor to a storage bin or directly to where it will be mixed with incoming sludge. The sludge system is made up of mechanical dewatering, cake conveyance to day storage, and conveyance to mixing with recycle and sawdust. The three components (sawdust, recycled compost, and raw sludge) are mixed mechanically and carried to the reactor by a conveyor/elevator.

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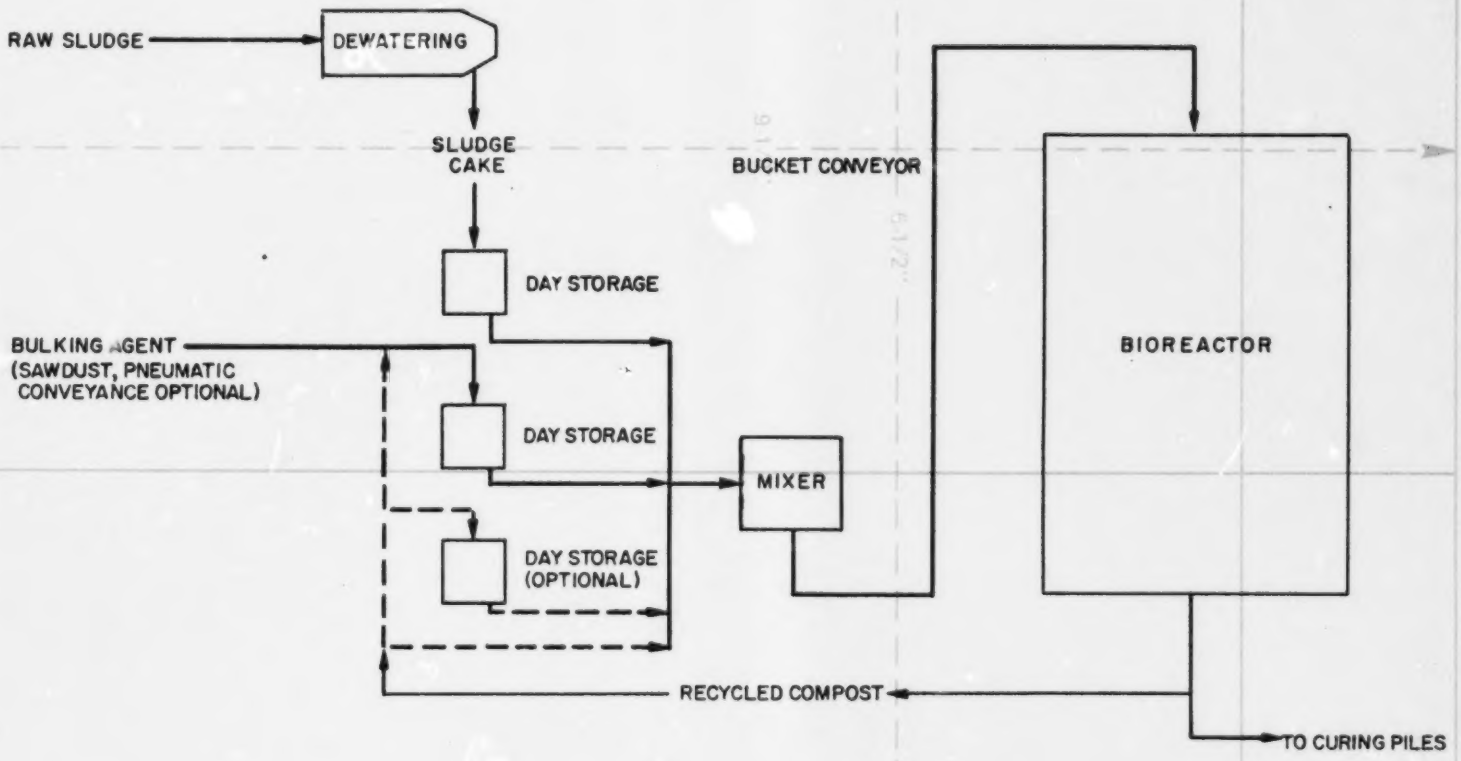

Figure 1. Process flow diagram for BAV composting system.

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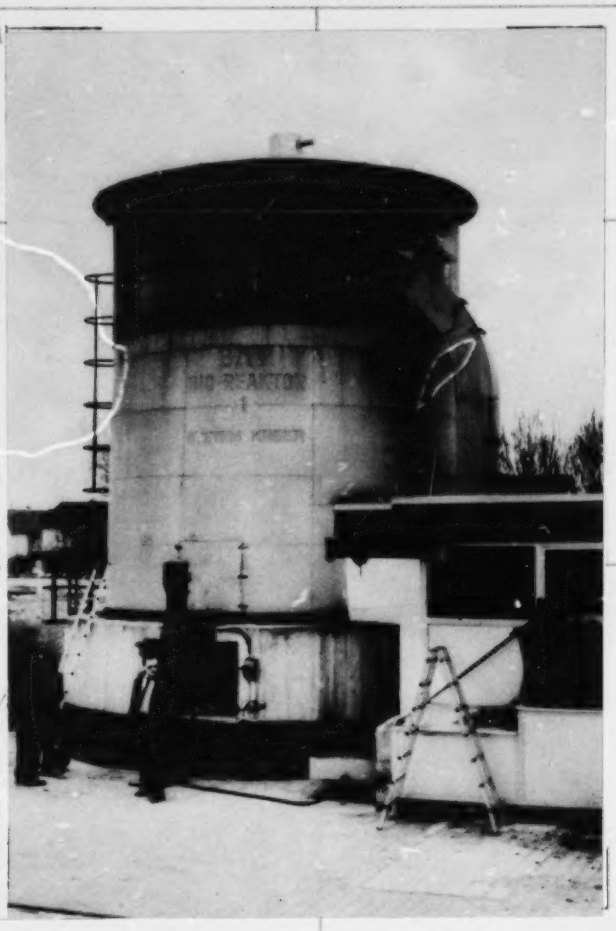

Figure 2. The BAV Bioreactor (Lambsheim, West Germany).

METHOD OF OPERATION

Selection of Bulking Materials and Ratios

From experience, a 35-percent input solids concentration is considered optimal for proper pore volume and the concomitant good air distribution. Various ratios of sludge to recycle compost to sawdust are usually tried. Sludge to recycled compost to sawdust ratios used range from 1:2:0.5 with a 20-percent sludge to 1:1:0.1 to 0.15 with a 30-percent sludge.

For good composting, a C:N (carbon to nitrogen) ratio of from 15:1 to 30:1 is desired. According to BAV, examination of samples of material added to bioreactors have shown them to have C:N ratios varying from 16:1 to 35:1 (BAV, 1978).

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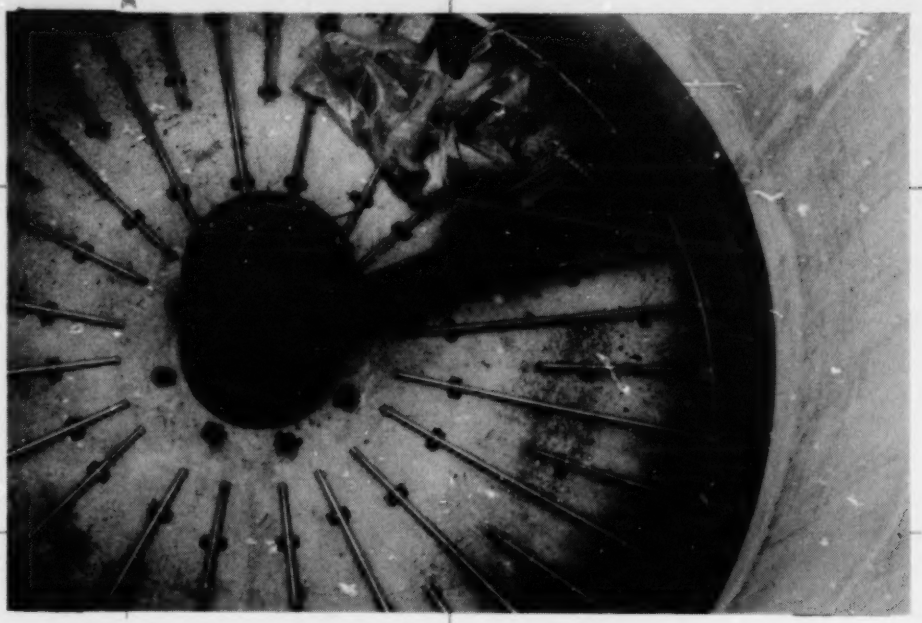

Figure 13. Extraction mechanism (Schluechtern, West Germany).

Procedure Used in Daily Operation

The bioreactor is operated in a daily batch withdrawal and fill manner. Except for any volume loss created by sludge/compost settling, a bioreactor should normally be full to the top. So, in order to create room to add a day's volume of sludge cake-sawdust-recycle to the reactor, compost must first be removed; then, the sludge-sawdust-recycle compost mixture is added. With practice, an operator can coordinate loading and unloading of the vessel so that they can be performed simultaneously. It is estimated that the batch withdrawal and fill procedure takes 3 to 4 hours of operator attention daily. This includes an hour to remove compost to curing piles and an hour to fill the reactor. Additional time may be required for removal of product from the site.

In addition to the batch operation of loading/unloading, the reactor must be monitored and controlled and ancillary equipment must be operated and cared for. The reactor environment is, in practice, monitored using temperature as the indicator, and is adjusted by controlling the operation time of the aeration system. Normal practice is to seek temperatures of 60°C or more for 4 days. Documentation at most plants is poor. The temperature recording equipment at the plants is rarely used.

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RESULTS OF THE BAV COMPOSTING

Observations

We found that, in general, operators are satisfied with the BAV system for composting. They were pleased with the mechanical performance of the system, with the level of staffing required for operation, and with the quality of the product.

Product Quality

The texture of the compost product after curing is very satisfactory. The product is not easily differentiated in appearance from a rich organic topsoil. The product is a deep brown in color and emits no foul odors, having an "earthy" smell.

Laboratory analyses have been performed on the compost product. The laboratory procedure, the results, and their interpretation are presented in Section 6. In general, the laboratory studies show the product, after curing, to be a well-composted sludge.

Product Utilization

In West Germany, most of the compost from BAV bioreactors is sold for use on private gardens and lawns, town-owned lands, or farms. The compost product from Freigericht is sold to a firm in France. This company ships the product to Saudi Arabia for use as a soil amendment or builder.

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SECTION 4

DETAIL OF THE BAV SYSTEM

OVERVIEW

BAV Composting System Installations

To date, BAV reactors are operating at 24 wastewater treatment facilities, all except one of which are located in West Germany. Two additional BAV facilities are presently under construction and one wastewater treatment plant (Hochheim) has a BAV reactor that is no longer in operation. A list of the BAV installations is presented in Table 1, which includes plant locations, the bioreactor unit sizes, the plant service populations, and the dates of completion. The locations of the West German facilities, with the sites visited designated, are shown in Figure 4.

Development of Equipment

Components of the BAV composting reactor system have evolved using experience gained from actual plant operation. Modifications have been made not only to correct failures at existing plants, but to improve the design of new facilities. As new plants were built, they were fitted with the new, improved equipment.

The development of the BAV reactor system is best traced component by component; this is the approach used in the following discussion. The information concerning the BAV bioreactor development was acquired in meetings with representatives of BAV and in visits to eight installations. The installations visited were: Eddersheim, Freigericht, Hochheim, Kronberg, Lambsheim, Lollar, Rosbach, and Schluechtern.

EQUIPMENT USED IN HANDLING CAKE, SAWDUST AND PRODUCT

Sludge Dewatering

Both belt filter presses and centrifuges are used at BAV installations. Experience has shown that a cake sludge solids concentration of 18 to 25 percent, prior to mixing with bulking agents, is best suited for the BAV

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TABLE 1. LIST OF BAV BIOREACTOR INSTALLATIONS

Plant Location	Date of Construction	WWTP Design Flow (Population Equivalents)	Volume of Bioreactor(s) (m^3)
Lambsheim, Rheinland-Pfalz	1973	20,000	100
Winterberg, Nordrhein-Westfalen	1974	20,000	100
Weilheim (Teck), Baden-Wurttemberg	1974	30,000	300
Gartringen, Baden-Wurttemberg	1974	15,000	100
Nantes, France	1975	100,000	600
Hochheim (Main), Hessen	1975/76	25,000	230
Kandel, Rheinland-Pfalz	1974	10,000	70
Vlotho, Nordrhein-Westfalen	1975	20,000	150
Kronberg (Taunus), Hessen	1977	30,000	250
Delbruck, Nordrhein-Westfalen	1975/76	30,000	300
Brilon-Messinghausen, Nordrhein-Westfalen	1976	10,000	70
Lubeck-Herrenwyk, Schleswig-Holstein	1976	15,000	100
Lollar, Hessen	1976	25,000	200
Steinenbronn, Baden-Wurttenberg	1976	15,000	100
Herbrechtingen, Baden-Wurttemberg	1976	25,000	300
Oberes Ferndorftal/Hilchenbach, Nordrhein-Westfalen	1976	100,000	2x375
Raisdof, Schleswig-Holstein	1976	10,000	60
Eddersheim, Hessen	1977	15,000	100
Rosbach v.d. H., Hessen	1977	20,000	150
Buchen, Baden-Wurttemberg	1977	20,000	200
Schefflenz, Baden-Wurttemberg	1977	25,000	200
Wilnsdorf, Nordrhein-Westfalen	1977	15,000	150
Hohr-Grenzhausen, Rheinland-Pfalz	1977	25,000	150
Freigericht, Hessen	1978/79	50,000	2x250
Waldenbuch, Baden-Wurttemberg	1979	20,000	150
Oslo, Norway	1980	-	500
Schluechtern, Hessen	1980	25,000	250

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Figure 4. Location of BAV facilities in West Germany.

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reactor. New BAV installations are being constructed with centrifuge dewatering, as a belt filter sometimes produces a sludge cake which is too dry. A mixture of sawdust, bulking agent, and too-dry sludge cake may form clumps, which compost poorly.

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If the solids concentration of the centrifuge cake drops below 18 percent, the sludge is gummy and difficult to mix with the bulking agent. In which case, more bulking agent is needed, resulting in increased expenditures for sawdust purchase.

At newer facilities, progressive cavity pumps are used to convey sludge cake from dewatering to storage. At older facilities, cased drag-flight conveyors are used; but wear, chain stretching, and problems with the conveyor housing at changes of direction has led to the use of progressive cavity pumping for cake sludge conveyance.

Sawdust Handling

Bulk storage and equipment to convey the sawdust to day storage make up the sawdust handling system. The bulk sawdust storage area size depends on the source of sawdust, its availability, and delivery schedule. The sawdust is stored directly on the ground or on a concrete pad. Large storage areas are usually open-air; small storage areas are usually roofed and surrounded on three sides by a cinder block wall.

At the majority of BAV installations, sawdust is moved by a front-end loader from bulk storage to day storage, which is indoors. The front-end loader dumps the sawdust into a hopper/chute, which leads to the day bin.

A pneumatic system, to convey sawdust to taller day storage bins, is installed at the Buchen and Freigericht facilities and is being installed at Schluechtern. It uses a front-end loader to move sawdust from the bulk storage area to the pneumatic system hopper, from which the sawdust is blown to a cyclone set above the day sawdust storage bin. The air and sawdust are separated by the cyclone, and the sawdust falls into the storage bin below.

The use of a pneumatic system and large day bins results in less frequent handling of the sawdust material then does the more widely-used direct loading system. Yet, in order to have "hands on" material ratio control, the operator at Freigericht still prefers to use a front-end loader to load the sawdust, along with recycled compost, directly to the conveyor.

Product Handling

At Lambsheim, the first facility constructed, compost removed from the bioreactor is conveyed from beneath the reactor by a cased drag-flight conveyor. The compost falls from the conveyor housing onto a portable belt conveyor. This conveyor carries the compost to the recycle compost day storage bin or to curing. When compost is to be cured, this portable con-

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veyor loads it on the vehicle that carries it to the curing piles. Sometimes, the portable conveyor is not used. Rather, compost is dumped, by the cased drag-flight conveyor, onto a concrete pad beside the bioreactor, and a front-end loader is then used to transfer it.

At the next 22 plants constructed, cased drag-flight conveyor systems are used to carry the compost to recycle storage. Reduced material handling makes this system an improvement over the original Lambsheim design. The type of conveyor used is shown in Figure 5. This conveyor can carry compost to the day recycle storage bin or directly to the vehicle which carries it to curing. A door in the conveyor housing, located between the reactor and the recycle storage bin, can be opened for discharging compost.

This cased drag-flight conveyor system has had problems similar to those of the cased drag-flight system used to convey the dewatered sludge. That is, chains have stretched, parts have worn out, and the housing of the conveyor has been scraped at bends.

We observed an improvement that has been built into the newer Freigericht facility. This improvement is also used at Waldenbuch, and will be used at Oslo and Schluechtern, plants presently under construction. A reversible belt, rather than a cased drag-flight conveyor, collects compost falling from the bioreactor. This belt can carry the compost either to a belt leading to the recycle day storage bin or to another belt that carries compost to a vehicle for transportation to curing.

If desired, volumetric measurement of the recycle compost going to combined storage with sawdust can be made using a front-end loader to dump the recycle compost and sawdust to a hopper emptied by another belt conveyor.

Storage, Mixing, and Loading of Dewatered Sludge, Sawdust and Recycle Compost

Storage and Conveyance to Mixing--

The first two plants built, Lambsheim and Winterberg, have the same type of day storage bins. Two steel storage bins are provided, one for raw sludge cake and the other for a combination of sawdust and recycled compost. The bins are located side by side, with a common wall. On the horizontal plane each bin is rectangular, but the outside of the bin is sloped so that, looking from the end of the bin, a vertical plane has a trapezoidal shape. The storage bins at all sites are fitted with level probes, to prevent bin overloading.

We visited the facility at Lambsheim. Each storage bin there is approximately 2.5 m long and 1.5 m wide at the top. At the bottom, the bins narrow to about 0.3 m. The bins at Lambsheim and at all other sites are designed for 1-day's storage.

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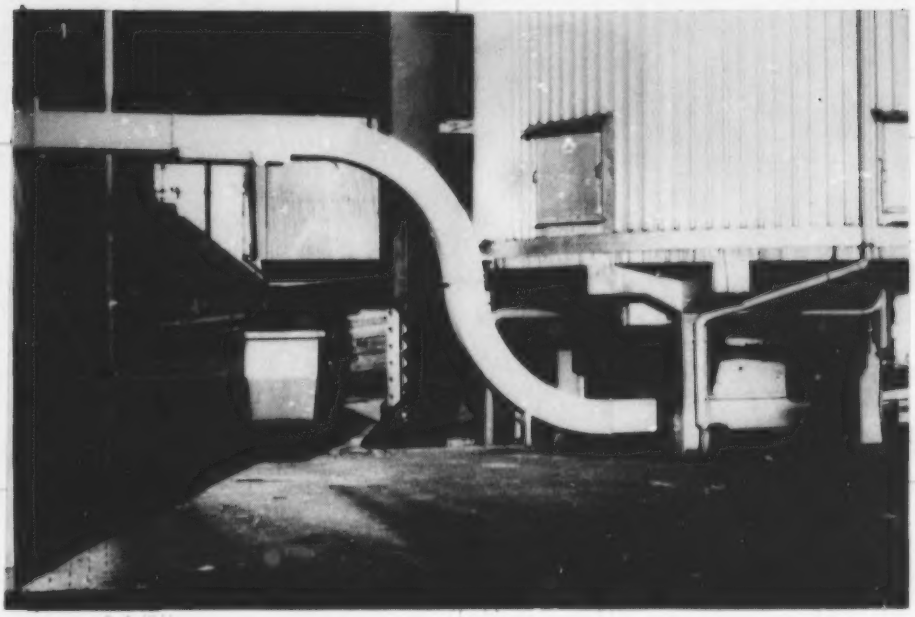

Figure 5. Cased drag-flight conveyor to day storage or to compost vehicle (Kronberg, West Germany).

A variable-speed screw conveyor, located at the bottom of each storage bin, is used at Lambsheim and Winterberg to carry the materials to a mixer. The speed of each screw conveyor is adjusted to control the ratio of the sludge to the recycle compost/sawdust in the final mixture. Parallel to the screw conveyor there is a pug-mill-type axle to break up the sludge or recycle compost/sawdust mixture.

In order to provide better control, there are separate storage bins for sludge cake, sawdust, and recycled compost at the next twenty-one BAV facilities constructed. Made of concrete, the bins are identical and each has an octagonal interior horizontal section. Bins were observed to be about 1.5 m across and 2.5 m deep at Eddersheim and Kronberg. They are set on the floor, at right angles to one another.

At the base of each bin is a five-bladed turning device. This mixer breaks up the solid material, allowing it to fall on a conveyor at the bottom of the bin. One hydraulic motor drives all three of the mixers. The motor activates pistons which turn a ratchet on the top of each mixer's shaft. By valve adjustments, the speed of each mixer can be controlled independently. The sawdust bin and the recycled compost bin mixers are operated at 0.5 to 1 RPM. The sludge bin mixer is operated at a much lower speed.

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Screw conveyors are used to convey each of the materials from storage. The only exception to this is at Kronberg, where a chain and flight conveyor is used to convey the sawdust. The conveyor speeds are independently adjustable for control of the sludge/bulking agent ratios.

At the four newest facilities, only two storage bins are provided. One is used for sludge cake alone, and the other for either sawdust alone or for a mixture of recycled compost and sawdust. The storage bins are roughly cubic. No mixer or breaker is necessary as each bin is fitted with a live bottom scraper. The speeds of each live bin bottom is independently adjustable. This provides control of the bulking material-to-sludge cake ratio. The materials removed from the bins fall to a common belt conveyor, which carries the materials to mixing.

At Schluechtern, the bulking agent day bin will not be used to hold a mixture of sawdust and recycle compost; sawdust alone will be held. The plant will not be provided with recycle compost storage. Recycle compost will be carried by a belt conveyor directly from beneath the bioreactor to the belt conveyor carrying sawdust to the mixer.

The sludge cake storage at Schluechtern is also of new design. The hopper has one vertical and three sloped sides which converge at a pipe at the hopper base. This pipe is approximately 15 cm in diameter. The cake is removed from the hopper to the sludge cake/bulking agent mixer by a progressive cavity pump. A progressive cavity pump has been selected for use at Schluechtern, because unlike a screw conveyor, it is closed, and does not allow a wet sludge cake to pass when not turned on.

Mixing--

At Lambsheim, we saw a double-axle mixer to combine sludge cake with bulking agents. Such a mixer is also installed at Winterberg, and is being installed at Oslo, Norway. Figure 6a shows a top view of the mixer housing at Lambsheim. Figure 6b shows a closeup of the mixer's axles. The mixer consists of two horizontal, parallel, bladed shafts that turn in opposite directions. The blades along the two shafts alternate, passing each other when the mixer is operating, to impart a shearing force to the sludge, as they are at an angle to the axle. The pitch of the blades is adjustable. A third shaft is being installed at Oslo to keep sludge balls from rolling along the top of the two mixing axles, and remaining unmixed. The materials are mixed and conveyed at the same time. The mixture leaves the mixer by falling into the conveyor to the bioreactor.

All other facilities use a mixer in a cylindrical housing located beside the day storage bins. This type of mixer is shown in Figures 7a and 7b. As shown in Figure 7a, conveyors carry sludge, compost, and sawdust into the top of the mixer's cylindrical housing. Figure 7b shows the rakes of the mixer. These rotate at 140 rpm or greater, driven by an 11-kw motor. As a safety precaution, the mixer automatically stops when the lid to the housing is opened.

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Figure 6a. Double axle mixer housing (Lambsheim, West Germany).

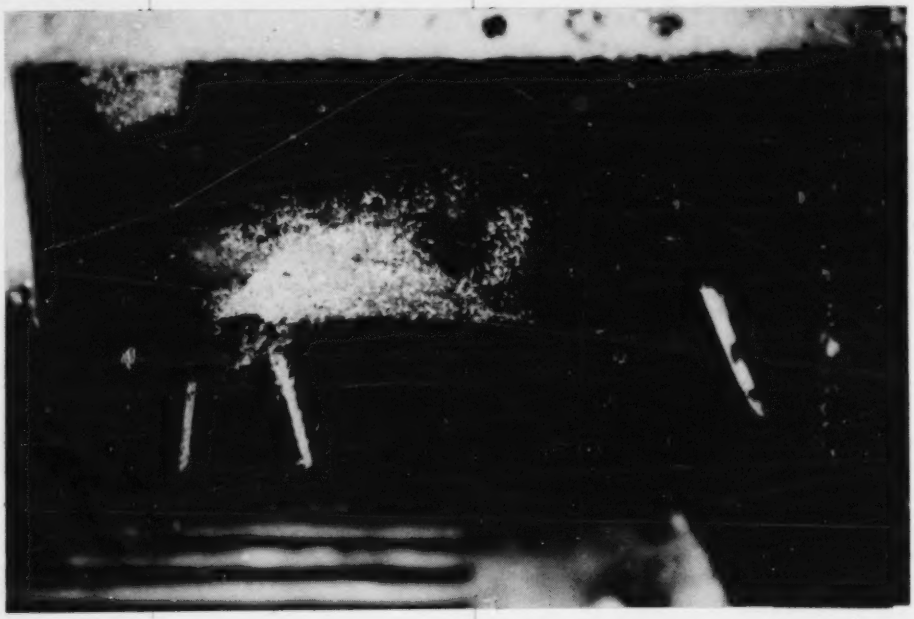

Figure 6b. Close-up of double axle mixer (Lambsheim, West Germany).

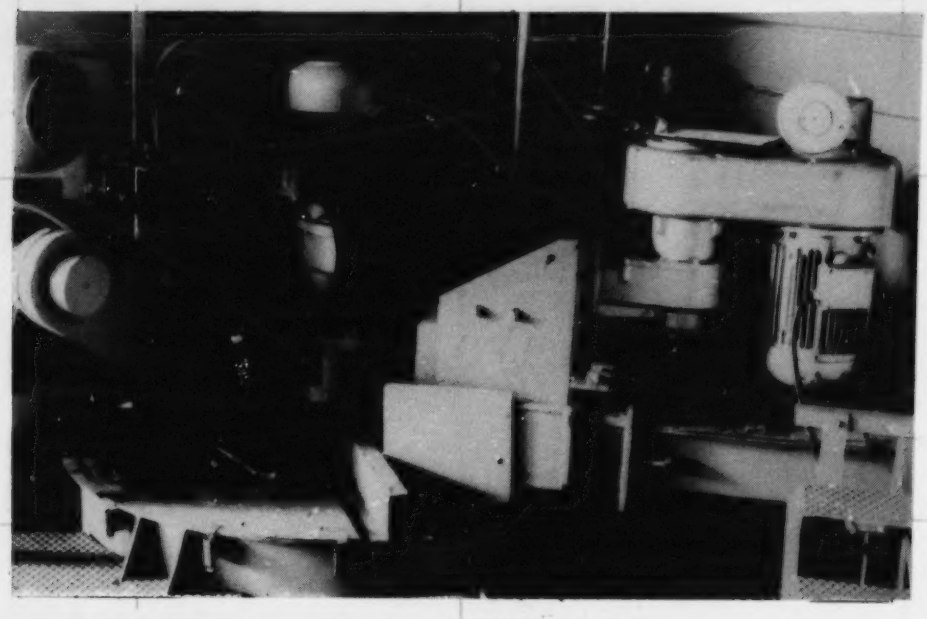

Figure 7a. Cylindrical cake sludge/bulking agent mixer (Kronberg, West Germany).

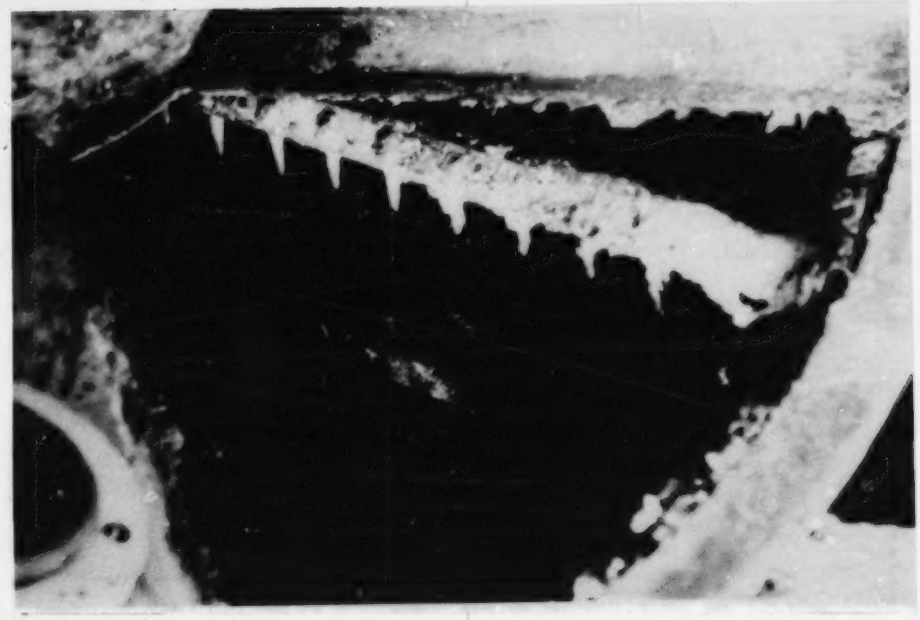

Figure 7b. Interior of mixer (Kronberg, West Germany).

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The materials are mixed for a period of approximately 0.5 minute before falling out of a hatch located in the bottom of the cylindrical housing. This hatch is located diagonally across the cylinder from the entry hatch to avoid the possibility of the materials simply passing through. The mixed materials fall from the mixer directly into the bioreactor-loading conveyor.

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Loading of Bioreactor--

A conveyor carries the mixture of sludge, compost recycle, and sawdust to the bioreactor. Two types of cased drag-flight conveyors were used in early designs. In the first system, the chain slides along the inner wall of the conveyor housing. The blades of the conveyor are connected to the chain and extend outwards to the outer wall of the conveyor housing. With this system, friction resulted in wear of the chain and housing. In addition, the sludge mixture tended to build up between the blades of the conveyor and the housing walls. In winter, the sludge mixture would freeze and the conveyor could not be started. "Frost watchers" were installed to prevent this, but were not regularly used by the operators. These "frost watchers", by operating the chain for a few minutes every hour, kept it moving freely.

The second type of cased drag-flight conveyor uses an improved chain and conveyor blade configuration. The chain itself, instead of dragging along one edge, sits in the center of the conveyor housing. The scraper blades extend out from each side of the chain. Conveyor wear was reduced, but not eliminated, by this system. In addition, the freezing problem remained.

In order to decrease the wear and freezing problems, chain and flight conveyors were abandoned. Bucket elevators/conveyors were installed at Freigericht and Waldenbuch, and are being installed at Oslo and Schluechtern. In addition, a bucket elevator/conveyor was installed at Kronberg to replace a worn-out chain and flight conveyor.

To prevent sludge sticking, the buckets are made of a plastic. The bucket elevator/conveyor, in a fashion similar to the chain and flight system, conveys the sludge mixture up the side and then across the top of the reactor. The mixture is loaded to the center of the reactor.

THE BAV REACTOR AND ANCILLARY EQUIPMENT

The BAV reactor and ancillary equipment are shown in Figure 8. A description of each component follows.

Reactor Body

The body of the reactor vessel may be steel or concrete. The selection of material depends strictly upon costs. The wall of the reactor is insulated, and clad with corrugated metal. All reactors are fitted, near the

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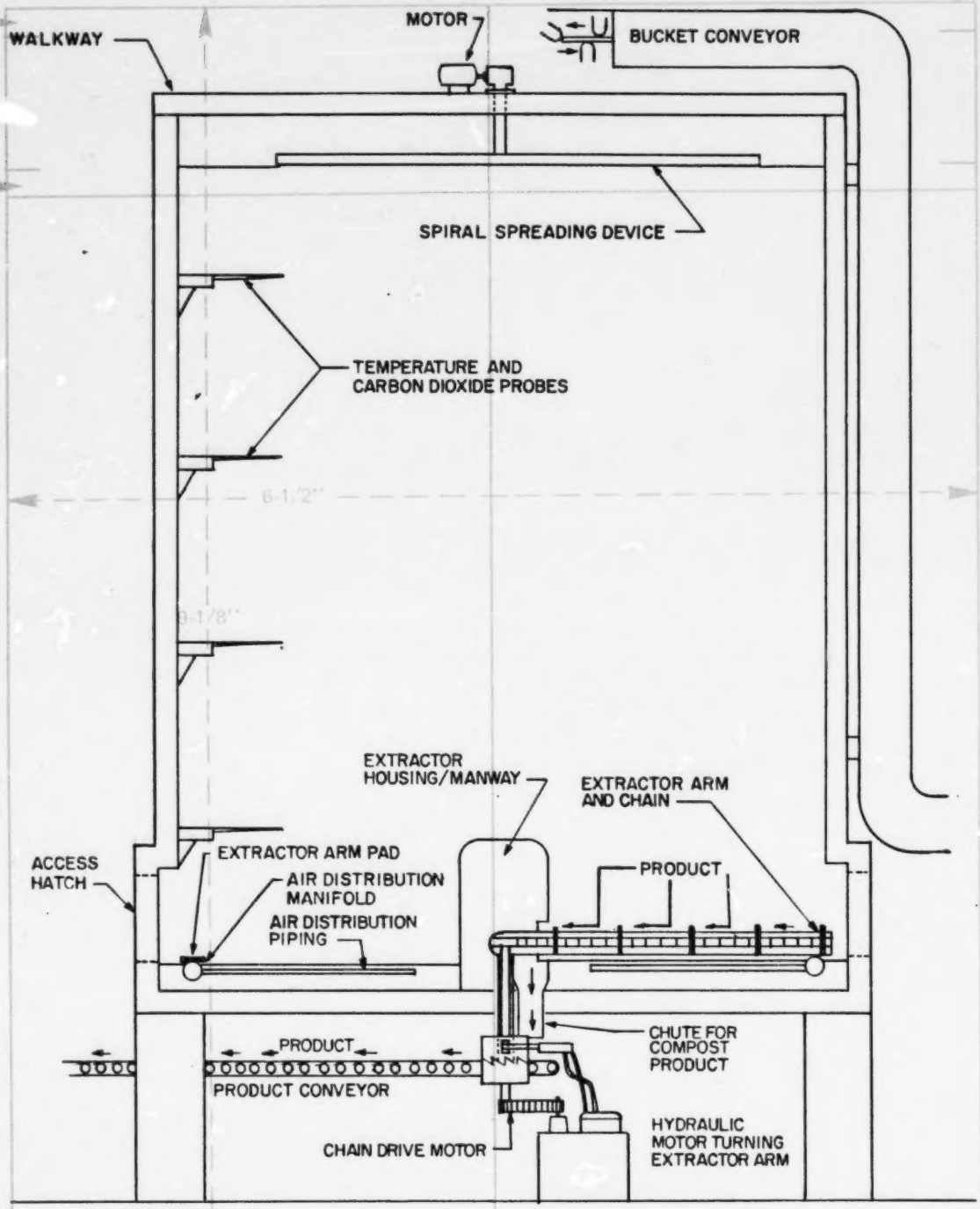

Figure 8. BAV bioreactor.

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base, with four hatches located 90 degrees from each other. These hatches are used for access to the collector mechanism and for emptying the reactor in an emergency.

The first 23 bioreactors, Lambsheim through Hohr-Grenzhausen, have sloped sidewalls. These reactors have a diameter at the base that is 50 cm larger than the diameter at the top. This slope was designed to help prevent the composting material from sticking to the reactor sidewalls.

Newer reactors at Freigericht, Waldenbuch, Oslo, and Schluechtern do not have sloped sidewalls. Instead, the bottom meter of the reactor sidewall is indented outwards about 0.25 m. This design is meant to help compost at the outer edge of the composting vessel fall to the compost collection chain.

Each reactor is covered with a roof, to protect the composting material from precipitation. The bioreactors at some facilities are completely enclosed at the top, by a roof with sidewalls, in order to contain any odors.

The floor of the reactor is a concrete slab. This slab is sloped, either towards the center or towards the outer rim, to allow for drainage collection. It is covered with about 40 cm of gravel, to aid reactor drainage and prevent compost from coming in contact with the aeration piping system. A drainage collection sump of approximately 20 litres is provided, and emptied through a manually-controlled valve. Freezing of the drainage system has been reported.

Monitoring Probes

Each bioreactor contains four temperature and four carbon dioxide probes. Temperature is critical to process monitoring and these probes have worked well. Nonetheless, temperature charts were not regularly used at any of the facilities that we visited.

To date, carbon dioxide monitoring has not been successfully used for process control. The high humidity of air within the reactor is believed to have caused the malfunction of these probes.

Aeration System

A system of air diffuser pipes is laid on the base of the reactor. As mentioned above, these are covered with a layer of gravel to prevent contact with the compost. This helps prevent the possibility of aeration pipe clogging and improves air distribution at the reactor base.

Three types of piping systems have been used for aeration. At early facilities, a system of concentric, air diffuser pipes are fed by one radial manifold. A later system consisted of a spiral-shaped air diffuser pipe fed at each end by the manifold; BAV thought that this configuration did

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not provide uniform air distribution. The third system used can be seen in Figure 3. It consists of capped air diffuser pipes of various lengths extending radially inwards from a common circular manifold. This manifold is located just inside the bioreactor wall around the entire vessel circumference.

Newer facilities are valved so that the blower can operate in either a suction or pressurization mode. BAV prefers to operate the system in a suction mode. In this mode, air may be filtered through a cured compost pile for odor control, and in the future, heat exchangers may be used to capture some of the heat produced in the composting process. In addition, with a moisture trap, suction can prevent the formation of fog at the reactor surface as the warm, moisture-laden exhaust hits cool air.

Sludge/Bulking Agent Spreading Mechanism

The mixture of dewatered sludge cake and bulking agent is dropped near the center of the bioreactor area by the loading conveyor. The mixture should be spread across the top of the bioreactor so that the surface of the composting mixture will lay flat, about 0.5 m below its rim.

Two types of spreading mechanisms have been used. Both types are driven by a motor set over the center of the bioreactor, on a platform that rests on the bioreactor's rim. Neither mechanism has adjustable height. Because of this, the mechanisms will not smooth the material to be composted unless the bioreactor is filled to capacity. Operators have been instructed to level the compost by hand if the material level is too low for the spreader to operate. We understand that this was rarely done. The easiest way to insure that the material will be leveled at the top of the bioreactor, is to make sure that sufficient material to fill the bioreactor is available.

The first type of spreading mechanism was installed only at Lambsheim. This mechanism is made up of a rotating raking arm that extends across the bioreactor's diameter. To this arm are attached blades that direct the material outwards to the rim of the reactor.

A spiral spreading mechanism, shown in Figure 9, is used at all other BAV installations. Again, this mechanism simply pushes material out towards the bioreactor rim. The spiral terminates about 0.5 m from the rim, so that material will not be pushed over the bioreactor's wall. There are "vee" notches along the bottom edge of the spiral, to allow some material to be bypassed.

Extractor Mechanism

The extraction mechanism can be seen in Figure 3. The extractor consists of a chain conveyor which moves along a guide arm. One end of this arm is fixed to a shaft centered beneath the reactor. The other end of the arm extends radially outwards to the edge of the bioreactor wall. When

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operating, the arm rotates about the base of the reactor to collect compost from all areas.

The mechanism has been a problem at some installations, so BAV has made several revisions to the design. (See Section 5 for an assessment of the mechanism).

Extractor Mechanism Drive Unit--

The initial system used at Lambsheim was purchased from a manufacturer of grain silo equipment. This unit was not powerful enough, and had to be replaced. The replacement Lambsheim unit, and all BAV plants built since then, use a hydraulic motor to turn the extractor arm. The motor drives the mechanism shaft by piston (as shown in Figure 10). The shaft is ratcheted, and thus consists of two portions. One portion is turned, back and forth by the piston, a rotation sufficient for the teeth of the ratchet to mesh one time. The second half of the ratchet, which is attached to the extractor arm, is turned by the first, piston-driven unit in a "stop and go" fashion. A typical speed of the extractor arm's angular rotation is one turn every hour.

Extractor Arm and Chain--

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The extractor arm is shown in Figure 3. Early designs required too much torque to turn the extractor arm and the extraction chain. These deficiencies caused the equipment to jam or break. To overcome these deficiencies, the extractor arms have been narrowed, the collector chain strengthened, and the collector blade size decreased. In addition, a "scraper" blade was developed, alarms added, and operating procedures changed. These changes are detailed below.

The first extractor arms used were 30 cm wide. Between unloading periods, compost rested on this arm and the weight of the compost would keep the arm from starting. To remedy this problem, a narrower arm of 15 cm is now being used.

The size of the extraction chain collection blade was reduced in later designs. It was found that a large collection blade puts too much strain on the drive chain. The collection blade presently being used consists simply of two horizontal "fingers" approximately 5 cm wide and 1 cm high. The chain itself has been strenghtened. The first chain had a breakpoint of 12 metric tons. New chains are designed with a breakpoint of 42 metric tons.

Additional protection was built in by adding a sharp scraper blade to the tope of the collection chain, to loosen compost resting on the extractor arm. This blade extends inwards, over the top of the extractor arm. To start the arm, the chain is first turned on. The scraper blade then frees the arm for movement.

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Figure 9. Spiral BAV bioreactor feed spreader, as seen from the bottom of an empty bioreactor (Schluechtern, West Germany).

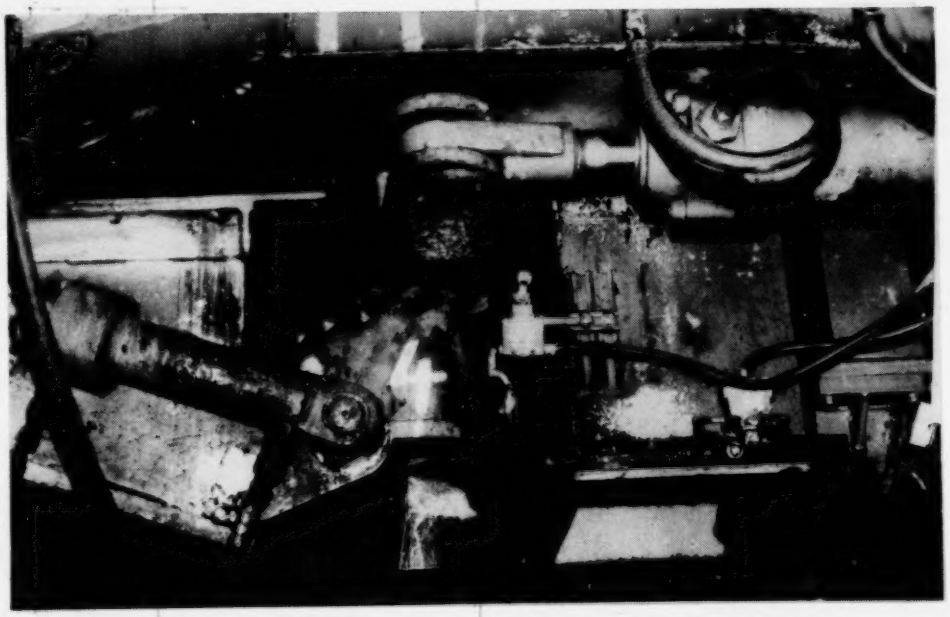

Figure 10. Piston and ratchet drive of extractor arm (Freigericht, West Germany).

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The actual design of the scraper blade itself has been changed with time. At first, a long blade was used; but with a long blade, compost would fall in clumps and caverns would form over the extractor arm. Later blade designs, which call for a smaller scraper blade (over a narrower, 15-cm arm), have provided a solution. An alarm, which notifies the operator of a jammed arm, has been added to the arm to prevent damage.

The first 25 plants constructed use an electric, one-speed motor, to drive the chain at 1 m/sec. The Oslo and Schluechtern plants are being built with a hydraulic motor for chain drive. This motor can vary the chain speed from 0 to 1 m/sec.

Extractor Housing--

At the first 25 facilities constructed, the sole purpose of the extractor housing was to keep compost from falling out of the extractor hole in the center of the bioreactor's base when the extraction mechanism was not being operated. These housings are cylindrical with a flat lid. The entire housing rotates with the extractor arm.

At Oslo, Norway, and at Schlechtern, the extractor housing is a domed structure. The diameter is about 1 m and the maximum height is approximately 1.5 m. Immediately above the port in the housing through which the extractor arm passes is a hatch, to provide access for chain repairs. As the plants with this design have not been put in service, use of this hatch has not been proven. The hatch is only 38 by 29 cm.

CURING

Experiments by various investigators and by BAV have shown that compost taken directly from the bioreactor is not fully "mature" (BAV, 1978). The compost that is removed from the bioreactor must go through a curing period of six weeks before the product is finished.

The curing sludge simply sits in a pile for the period required. There is no aeration and piles are not turned. To assure a sufficient oxygen supply, piles should be piled loosely and no greater than 1.8 m high (BAV, 1978). There is no cover or building protecting the piles. They may sit on a concrete pad or directly on soil (Figure 11).

There is also no monitoring at sites to test the "completeness" of the product, though one operator does check fungus growth to measure the degree of curing achieved. The results of tests such as those described in Section 5 have shown 6 weeks of curing to be sufficient.

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Figure 11. Curing pile of BAV product (Freigericht, West Germany).

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SECTION 5

EVALUATION OF CRITICAL COMPONENTS

INTRODUCTION

This section evaluates equipment that has had mechanical and operational difficulties.

EXTRACTION MECHANISM

Mechanical

As a result of tests run at Hochheim by Battelle, the extraction mechanism was identified as a major source of difficulty with the BAV bioreactor. Four major breakdowns of the Hochheim extraction mechanism were reported: the extraction chain broke, the arm of the extractor was bent upright, and the arm stopped twice due to buildups of solidifed material at the reactor's base. In each instance, to allow repairs, the entire bioreactor had to be emptied by hand, a time-consuming procedure.

Much of the difficulty at Hochheim can be attributed to the poor dewatering of the sludge prior to insertion into the bioreactor. The sludge had only been dewatered to 9 to 13 percent solids. With such a wet, gummy sludge, the buildup of a solid mass at the bottom of the bioreactor occurred, and was largely responsible for the mechanism failure.

In addition to the problems reported at Hochheim, operators interviewed at the five other installations visited by Battelle all reported difficulties with the extraction mechanism. At all the plants that we visited, extractor chain repair was considered to be a regular maintenance item, and repair or replacement was required about once a year.

BAV has taken a number of steps to improve the operation and simplify repair of the extraction mechanism. These improvements, described in detail in Section 3, are:

- use of a narrower extractor arm, to decrease the contact area with the compost;
- use of an alarm to warn operators of extractor arm overload;

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- use of a scraper blade on the collection flight, to loosen compost that may restrict arm movement;

- use of a variable speed motor to drive the collector flight;

- redesign of collection flight blade;

- redesign of the extractor housing, to increase access for repair; and

- strengthening of the extractor chain.

Without the test of time, it is difficult to say whether or not these changes will greatly improve the performance of the extraction arm. The use of a narrower extraction arm may decrease the frictional forces on the arm, but this provision does weaken the arm's strength. The alarm and the strengthening of the extractor chain can only help performance. Redesign of the collection flights and the addition of scraper blades to the extractor may also help. The provision of a variable speed motor can only improve performance if used properly by the operator.

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To allow repairs to take place without emptying the reactor, 4 access hatches have always been provided in the wall of the reactor vessel. However, these cannot be used unless the arm is stopped in front of one, and even if the arm stops at an access hatch, tunnelling to reach the arm requires careful bracing with a wooden frame.

The provision of a domed extractor housing may not greatly reduce the difficulty of extractor arm repair. Although such a housing will always provide access, as the door revolves with the extractor arm, the following will limit its usefulness:

- the passageway to the hatch is very small, and furthermore, it is restricted by extractor arm components. Wooden bracing for the necessary tunnel will not pass through it;

- the hatch is covered by a heavy, difficult-to-remove lid; and

- the work area within the extractor housing allows little room for either the start of tunnelling or for the repair of parts within the housing.

Short Circuiting

Battelle stated that, at Hochheim, short circuiting occurred within the reactor. This occurred when the sludge/bulking agent mixture built up on the sidewalls of the reactor, reducing its effective volume. As a result of this short-circuiting, the performance of the Hochheim bioreactor was poor; compost removed from the bioreactor was immature and odors were present. The desired constant high temperatures could not be maintained. The cause of these problems was largely the poor performance of the dewatering

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system at Hochheim, rather than bioreactor design. In addition to causing short circuiting, the wet, sticky sludge was difficult to aerate.

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The design of the extractor mechanism does not, however, insure that plug flow occurs. The extractor arm pivots at the center of the reactor. Portions of the arm located farther from the pivot move much more quickly across the base of the bioreactor than do the portions at the center of the bioreactor. Because of this, the extraction chain can be expected to remove a greater volume of compost per unit area at the center of bioreactor base, with decreasing volumes per unit area removed closer to the bioreactor wall. As a result, compost taken near the center of the bioreactor base may have had a shorter composting or detention time than that taken from outer portions.

BAV has stated that they have run a limited number of tests that show the above hypothesis to be untrue. These tests involved the addition of recoverable solids, such as styrofoam balls, to the top of the reactor. The removal of these solids by the extractor mechanism was monitored. The test results showed that substances added at the bioreactor's rim had the same detention time within the bioreactor as substances added at the center. Unfortunately, documentation of test procedures and results has not been submitted to us.

Another test which could be performed would be the simple observation of the sludge level at the top of the reactor while the extractor mechanism is in operation. If the sludge in the center falls more rapidly than sludge at the walls of the reactor, short circuiting is occurring.

DAY STORAGE BINS

Sludge

There were no reports that removal of a 20-percent sludge from the day storage bins has caused any major difficulties. To date, the storage bins used were all fitted with some type of bridge-breaker or mixer. Sludge removal has normally been by screw conveyor.

At Sluechtern, which is presently under construction, a new design is being installed. BAV has replaced the screw extractor because sludge cake has "oozed" out of storage during system shut-down. At Sleuchtern, no bridge-breaker or mixer is being provided and sludge removal is to be by a progressive cavity pump. This system has not been tested. It appears to us that removal of the sludge with this new system may be difficult.

Sawdust

Battelle reported that, at Hochheim, a number of breakdowns of the screw conveyor removing sawdust from day storage occurred; this was attributed to the sawdust being damp. To remedy this problem, care is now being taken to

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prevent the addition of a wet sawdust mass to the day storage bin. The improvements include the use of a cover for bulk storage and screening of sawdust.

An additional improvement has been the use of a new sawdust extractor, the live bin bottom. This system, described in Section 3, has worked well to date.

MIXER

There have been some breakdowns of the high-speed mixer used to mix cake sludge, sawdust, and recycled compost. The major source of breakdown has been the insertion of large wood chunks with the sawdust that is added to the mixer. Stricter control of sawdust quality has been instituted in an effort to control this problem.

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SECTION 6

DEFINITION OF COMPOST

TESTING FOR COMPOST MATURATION

There are obvious differences between sludge cake and compost. These differences include, for example, odor, texture, and moisture content. In addition, seeds which might have been present in the sludge cake will not germinate after the material has been composted. The question remains, however, as to just when sludge actually becomes compost. The answer to this question is needed to tell whether a bioreactor or any other composting unit is working or not.

BAV occasionally engages two separate consultants to run tests on product from BAV bioreactor installations to determine whether the sludge has, indeed, been composted. These consultants are Dr. Fritz Balzer and Dr. Peter Chrometzka. Dr. Balzer is a private consultant living in Amonau, West Germany. Dr. Chrometzka is a professor at the University of Saarbruecken, West Germany. We interviewed these two scientists and also reviewed some of their pertinent publications.

Eight types of tests are run on the compost samples. These are:

1. Growth Tests
2. Humic acid composition tests
3. Fluorescence tests
4. Identification of cultures
5. Oxygen uptake rate
6. Ammonia and sulfide content
7. Carbon/nitrogen ratio
8. pH

In addition to these, the samples are, of course, inspected for color, odor, and general appearance.

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Growth Tests

Both Dr. Balzer and Dr. Chrometzka test the growth of watercress plants in the samples. The percentage of seeds germinating and the rate of plant growth are a measure of the quality of the compost. Stabilized compost promotes plant growth while sludge or fresh compost inhibits it. Dr. Balzer runs his tests on mixtures of sand with compost or sludge. Various ratios of sand to sample are used. The sand serves as a control. Dr. Chrometzka, on the other hand, plants the seeds in the sample alone.

In his tests, Dr. Balzer notes the color of the roots (white, brown), and the direction of root growth, in addition to the percentage of plants that germinate and how well they grow (quickly, normal, reduced). The color of the roots should be white. If the root is brown, the compost may be injuring the plant. From the direction of plant growth, it can be determined whether the compost is too hard for the roots to grow properly.

Humic Acid Composition Tests

Various classifications can be used to group the types of humus materials. One method, used by Dr. Balzer, distinguishes between fulvic acids, brown humic acids, and gray humic acids. Humic acids are more stable than fulvic acids, and as time progresses, the ratio of humic acids to fulvic acids increases.

Measurement of light absorbance at various wavelengths is used as a tool to develop ratios indicating the relative concentrations of fulvic acid to humic acid (Balzer, 1980; Y. Chen et al, 1977). Samples are extracted with sodium hydroxide. Balzer determines the quotient of absorbances at 472 nm and at 664 nm, calling it the Q 4/6 ratio. Chen et al determined their E_4/E_6 ratio as the quotient of wavelengths at 465 and 665 nm. With the Q 4/6 ratio, Balzer determines the predominant acid form; brown humic, gray humic, or fulvic acid. The predominant form indicates the degree to which sludge has been composted.

There are further details to the acid composition tests run by Dr. Balzer. These are regarded as proprietary and have not been made available to us.

Fluorescence Tests

In a book by F. W. Pauli (1967), a technique for the examination of decomposing materials by observation of fluorescence is described. Pauli states that nearly all cell structures produce a delicate fluorescence when irradiated by ultraviolet light. The color and intensity of this fluorescence is a measure of the materials present and can be used to evaluate a compost. Fresh materials tend to fluoresce while decomposed materials do not. The greater the color intensity, the less the decompostion. Colors vary with the type of material. Lignins fluoresce a yellow color while celluose fluoresces a bright blue.

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We were able to see Dr. Chrometzka perform an example experiment. A small sample was placed on an ultraviolet glass slide. A drop of water was placed on the sample and it was covered with a glass slip. The sample was then examined under a microscope.

The determination of fluorescence is based on the judgment of the observer. To prevent prejudicing his thinking, Dr. Chrometzka tests samples received in coded containers. We were told that samples with a high or average fluorescence impedes plant growth. Material with little or no fluorescence is well composted and does not impede plant growth.

Identification of Cultures

Dr. Chrometzka makes cultures to determine the contents of fungi, actinomycetes, and higher organisms. From past experience, he knows which organisms should be present in a mature compost.

While composting, various forms of life colonize within the material (Chrometzka, 1975). After a few days of composting, temperatures may reach 70°C or greater. With the occurrence of such a high temperature, the material enters what Chrometzka calls the "Actinomycetes Phase." At the beginning of this phase, various forms of actinomycetes, especially Actinomyces farinosus, appear. With further intensive composting of the material, other actinomycetes form, especially A. globesporus and A. flavus, appear. The occurrence of fungi is possible.

With a lowering of temperature, mites and collembola appear in large numbers. Their feeding habits contribute to a further degradation of organic substances. Larvae of manure flies may be present, and the hatching of these should take place before the compost is considered mature. Composts may be designated as mature when the rapid decompostion of organic substances, which is characteristic of a fresh sludge, no longer occurs (Chrometzka, 1975). Typical soil inhabitants, bacteria, actinomycetes, fungi, algae, Enchytraen spp., Collembola spp., mites and earthworms, colonize the compost. They work to their full effectiveness after mixing into an impoverished soil.

There are no hard and fast rules as to what organisms must be absent or present in a matured compost. However, some operators at BAV installations check the growth of fungus in the various profiles of curing piles. They use their observations as an indication of the maturity of the compost. Some operators consider the compost to be fully cured only when a dense fungus growth is produced.

Oxygen Uptake Rate

For a compost to be mature, all readily decomposable materials should have undergone humification. Only materials more difficult to degrade, lignin for example, should remain. These remaining organics will continue to undergo slower decomposition. The oxygen demand of such composts drops to

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below 30 $mm^3/g/hr$ (Chrometzka, 1975). At this level of demand, the product has a high storage capability without the danger of achieving anaerobic conditions.

Ammonia and Sulfide Contents

According to Chrometzka, the ammonia content is a good indicator of decomposition. During composting, ammonia builds up for about three to four weeks before dropping. Stable compost is low in ammonia. Nitrogen is present in the nitrate form, with the exception of nitrogen atoms bound in the high polymer humus molecules generated. Sulfides are not detectable in a compost.

Carbon/Nitrogen Ratio

Chrometzka considers the carbon/nitrogen ratio to be an important parameter. Sludge, with sawdust, might have a carbon/ nitrogen ratio of as high as 70 - 80 to 1. During composting, the carbon to nitrogen ratio may drop by about 25 percent.

pH

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According to Chrometzka, pH is proportional to ammonia content, and so increases, sometimes up to 9.0, when sludge cake starts to decompose. Stable compost, with a decreased ammonia level, has a pH of about 6.5, and not higher than 7.5.

Other Conditions

The compost must be free of viable pathogenic bacteria and plant seeds with the ability to germinate. The material ideally has a high water-holding ability. The material should have an "earth-like" smell and appearance and should have small enough particle sizes to allow it to be used agriculturally. On the basis of the high-polymer humus compounds and organo-mineralic complexes (clay - humus complexes) present, the material should have a high adsorption and high cation-exchange capability (Chrometzka, 1975).

DATA FROM BAV COMPOSTING

Detailed tests of BAV compost maturation are not run on a regular basis. The only regular indicators of compost quality are those compiled by simple inspection. These include texture, odor, color, and possibly, fungus growth. When run, the more detailed tests are not conducted at the plant sites, but are conducted by Dr. Balzer or Dr. Chrometzka. Unfortunately, complete sets of data sheets showing compost quality at various stages for

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a given plant are not available. We were, however, able to acquire sample data sheets from both investigators.

Table 2 is an example of the form returned by Dr. Balzer after a test is run. The data presented in this table are values for samples from three BAV facilities.

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TABLE 2. DATA FOR BAV COMPOST AS REPORTED BY F. BALZER

Location	Eddersheim	Freigericht	Winterberg
Date	11 October 1977	29 November 1978	29 November 1978
% Water	41.9	63.4	58.4
% Volatiles	62.3	72.7	66.3
Total Nitrogen (%)	1.58	1.05	1.31
Phosphorus, P_2O_5 (%)	2.66	0.85	2.93
Potassium, K_2O (%)	0.16	0.22	0.19
Magnesium, Mg (%)	0.44	0.41	0.84
Calcium, Ca (%)	4.78	1.37	0.95
Salt Content, (%)		0.085	0.54
Specific Gravity		0.518	0.567
Kresse Test			
Germination (%)	94	97	normal
Growth	normal	normal, white root	normal

Table 3 is a datasheet from a test run by Dr. Chrometzka. Data from seven other random BAV compost samples are presented in Appendix B.

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TABLE 3. DATA FOR BAV COMPOST AS REPORTED BY P. CHROMETZKA

Investigation of Composting Sample

Sample Number: 76/BAV/12/4

Test Date: 23 December 1976

Sampling Location:

Gartringen, after 14 days in Bioreactor and 4 weeks in curing piles.

Results of Analysis

1. Water Content: 68.01%
2. Organic Content: 67.24%
3. pH: 5.6

Plant Compatibility Test:

a. Sprouting: 98%

b. Growth: very good

c. Compatibility of Cress in this Sample: very good

Physical Observations:

4. Fungus Growth: little
5. Structure: coarse, lumpy
6. Odor: light, earthy
7. Appearance: earthy color

Microscopic Examination:

8. Degree of Organic Substance Humification (Microscopic fluorescence test described by Dr. Pauli):

[ ]	Strong fluorescence = very little decomposition
[ ]	Medium strength fluorescence = medium decomposition
[X]	Low strength fluorescence = extensive decomposition
[ ]	No fluorescence = very strong decomposition (up to 50%)

9. Principal Microorganisms in Composted Sludge (Investigation after 3 days of Aeration):

a. Bacteria: Stemphylium Species (+) (v) Scattered Incidence
Stysanus Species (+)

b. Fungus: Cephalosporium Species (+) + Lightly Dispersed
Aspergillus Species (++) ++ Numerous
+++ Densely Dispersed

c. Other Small Organisms: Milben (v)

10. Test Comments:

The cake is in a state of good maturity. The disintegration of the organic substance has strongly progressed through an actinomyces phase developed at an optimum level. The subsequent fungus phase has been achieved; the early Milben indicates suitability of materials for sale.

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The data presented in Table 3 and in Appendix B are for compost samples removed from BAV reactors and cured for from eight days to five weeks. Samples were generally described as brown, moist, and earthy or peat-like, with a dirt-like smell. A few samples had sour or sludge-like odors. Various degrees of fungus growth, from none to semi-strong, were reported.

Growth of watercress plants was reported to be good to very good; ninety-four percent of the planted seeds germinated. Fluorescence tests showed the samples to have undergone either medium or extensive decomposition. Microbial investigations showed that composting of the samples had, at a minimum, begun. The onset of fungal colonization had occurred in most samples, with some growth of higher organisms.

In general, the compost samples appeared to be either at or near maturity. These results coincide well with the selection of a 6-week period for sludge removed from the bioreactor.

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SECTION 7

COST OF BAV COMPOSTING

INTRODUCTION

In the report prepared for EPA by Battelle, a cost study of the Hochheim facility was presented. Two estimates were given: an estimate based upon data prepared by BAV and actual Hochheim bid data, and a cost estimate prepared by Battelle using the Hochheim specifications and operation and maintenance requirements estimated during their tests at Hochheim. The capital cost estimate prepared by Battelle was 75% greater than the value given in the BAV data. Operation and maintenance costs prepared by Battelle were 162% greater than those of BAV.

Cost estimates in the Battelle report were higher, because they were prepared for an entire sludge processing train, including: sludge thickening, conditioning, pumping, and dewatering. In order to determine the cost of BAV composting alone, these additional costs would have to be removed.

EPA asked us to calculate new costs for BAV composting. There were two reasons for this request: first, the wide difference in cost in the two estimates presented by Battelle and second, the need for costs of the BAV composting system by itself, and not for the entire sludge processing train. We have prepared these new costs by reevaluating the data presented by Battelle. We have also used additional information supplied to us in a meeting with representatives of BAV.

CAPACITY OF THE FACILITY

The 250 m^3 bioreactor at Hochheim was designed to handle 2.9 dry metric tons of a 20 percent sludge per operating day. This design was based on a 1.0: 0.8:0.2 sludge/recycle compost/sawdust ratio. In actual operation during the Battelle study, the reactor was apparently being loaded to its capacity at a rate of 2.2 dry metric tons per operating day with a 1:1:1 ratio.

Because the Hochheim bioreactor was not operating properly, we reevaluated the capacity of the 250 m^3 bioreactor. To do this, we made the following assumptions, at the recommendation of BAV:

- a 14-day detention period within the bioreactor

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- a 1.0:2.0:0.5 sludge/recycle compost/sawdust ratio (by volume) for a 20 percent sludge

- a 15-percent volume loss in mixing

- a 30-percent volume loss due to settling in the bioreactor

In addition, the bulk density of the 20-percent sludge cake was assumed to be 1.0 metric ton/m^3.

Based on these assumptions, the capacity of a 250 m^3 bioreactor was estimated at 1.7 metric tons per day. Operating costs were based on a 5-day week for sludge handling operations. It is assumed that sludge accumulated over a weekend would be worked off during the week by feeding at average rate of 2.4 metric tons per working day. The overall residence time would be unaffected.

CAPITAL COSTS

Table 4 is an item-by-item capital cost listing for equipment and other items required in a BAV composting system. The total capital cost for the 1.7 dry metric tpd system is estimated to be $653,600 (May 1980). These raw costs were derived from bids for an entire sludge handling system received by the Hochheim town administration in 1976. They were reported as an Appendix to the Battelle report. The values in the table apply to the BAV system alone. Costs have been adjusted to account for inflation and for currency exchange from Deutsche Marks (DM).

The total bid to the town of Hochheim for the sludge treatment and composting equipment was 1,370,000 DM. Of this, 862,000 DM was for BAV composting equipment listed in Table 4. At the time of construction, early 1976, the exchange rate was 2.6 DM per dollar. The bid for the composting equipment was thus, at that time, worth $332,000. With a United States inflation rate of 1% per month from January 1976 until May 1980, this cost has increased by 67% to $554,000.

To determine the complete capital costs, additions to the bid price must be made. We have assumed that the Hochheim bid included a contractor's fee and funds used during construction. The bid did include startup costs and working capital. We have, however, added a $17,000 licensing fee for the reactor (based on the calculated reactor capacity) and a 15% allowance for contingencies. This, when added to the bid cost, results in the estimated capital cost of $653,600.

BAV gave us capital cost estimates for composting systems of various sizes. We have taken these costs and adjusted them, as needed, to correlate with the detailed cost estimate presented for the 1.7 tpd system. The results are shown in Figure 12. The curves represent estimated costs for systems with either one or two bioreactors. The point at which the transition to a two bioreactor system is shown is at a total bioreactor size of 500 m^3.

TABLE 4. CAPITAL COST OF 250 CUBIC METER BAV SYSTEM

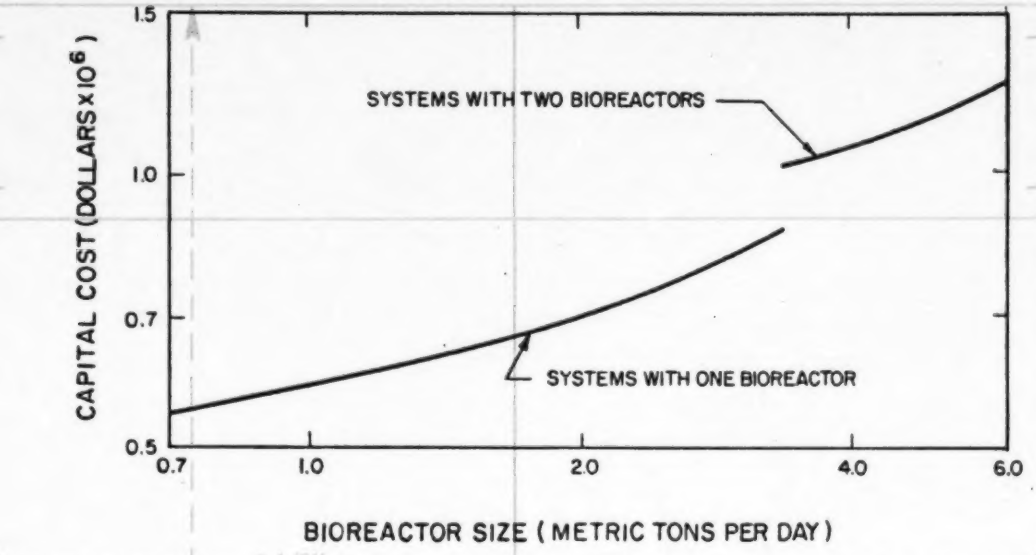
Item	Cost
Conveyor from Centrifuges	$ 34,400
Sludge Screw Conveyor	14,000
Product Screw Conveyor	14,000
Sawdust Bunker	16,700
Sawdust Conveyor	6,200
Rotary Mixer	19,100
Bucket Conveyor	27,000
Blowers	32,600
Ventilation Pipes	7,600
Bioreactor	77,100
Temperature Measurement System	5,000
Level Indicator	4,400
Extractor	43,200
Windrows (Paving)	18,200
Gas Measurement System	8,800
Building and Day Bins	129,000
Foundation for Bioreactor	14,100
Excavation Work	25,000
Electrical Installations	31,700
Paving	7,300
Ancillary Services	18,200
SUBTOTAL-EQUIPMENT COSTS	$553,600
Licensing Fees	17,000
Contingency (15%)	83,000
TOTAL CAPITAL COSTS	$653,600

OPERATION AND MAINTENANCE COSTS

The estimated annual operation and maintenance cost for a 1.7 dry tpd BAV composting system is $49,100. This is a cost of $79 per dry ton. The cost for operation and maintenance includes an allowance for the income obtained through the sale of compost.

Costs of Operation and Maintenance

A breakdown of estimated operation and maintenance costs is presented in Table 5. This breakdown identifies each of the three sources used in this evaluation: Battelle, Hochheim bids, and BAV. Also shown in the



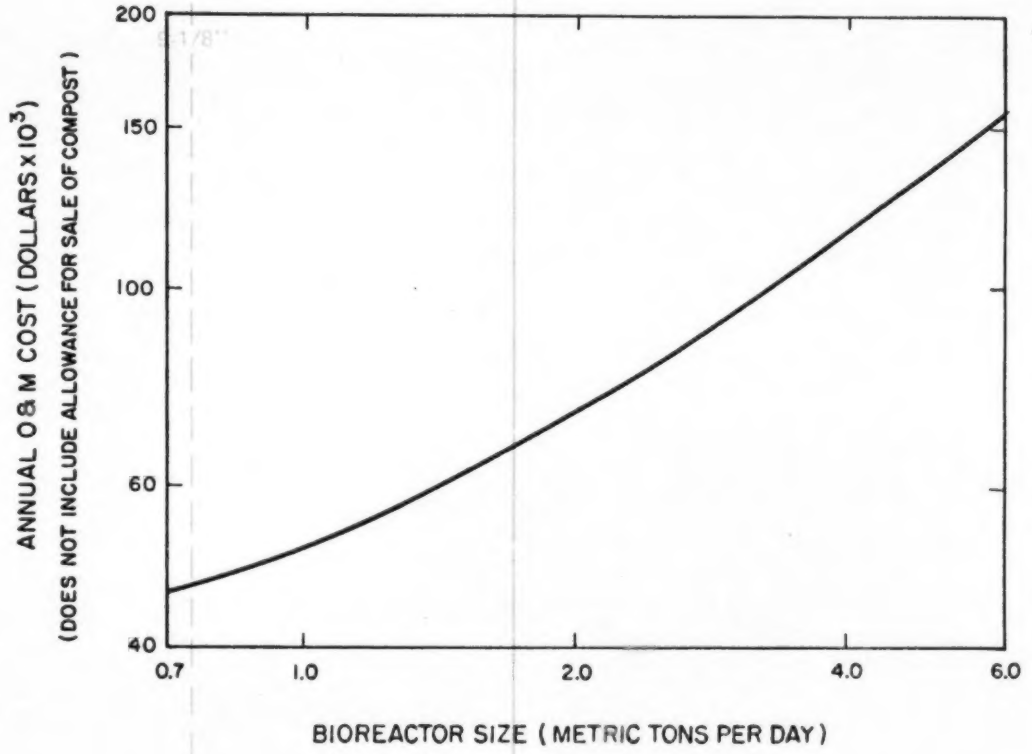


Figure 12. Estimated costs for BAV composting.

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table are assumptions made as to the number of hours worked, salaries, frequency of repairs for key items, and supply costs. This study assumed that the system was operated 5 days a week.

We have taken the calculated total annual cost of operation and maintenance for the 1.7-tpd facility, and from it have projected costs for facilities of other sizes. The results of this projection are presented in Figure 12. The costs shown in this figure do not include the allowance for compost sale given in Table 5, as the marketability of the compost in the United States has not been proven.

Income Received from Sale of Compost

In Germany, the treatment plant may receive 10 to 20 DM (about $6 to $12, May 1980) per cubic meter of compost solid in a bulk lot. The compost is normally picked up by the user. The compost product is also sold in bags to private gardeners. At one facility, the purchase price is 60 DM (about $35/m^3) when sold packed in 50-liter bags. At a second installation, the price is 38 DM (about $22/m^3) for an 80-liter bag. If the purchaser supplies and loads his own bags, this cost is reduced to 25 DM (about $15/m^3).

In our cost estimate, shown in Table 5, we have assumed that the facility would be able to sell all the compost it produces in a bulk lot. The compost is sold at $6/m^3 and picked up at the expense of the purchaser.

TOTAL ANNUAL COSTS

As shown on Table 6, total annual costs, including amortization and operation and maintenance, for a 1.7 dry ton per day BAV composting system is about $105,000. Equipment and buildings were amortized at an interest rate of 7 percent. Equipment was amortized over 20 years; structures, over 40 years.

The unit cost for composting by the BAV process is about $170 per ton. This cost is within the range of unit costs for other processes for composting centrifuge cake under cover at about the same rate, after allowing for sale of compost. Windrow and static pile composting without a roof would be less expensive.

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TABLE 5. OPERATION AND MAINTENANCE COST

OPERATION

Item	Source	Annual Cost
Sawdust ($9/m^3)	BAV	$14,000
Water	Hochheim	300
Electricity ($0.06/kwh)	BAV	5,500
Labor ($10/hr including fringes)	BAV	10,400
Supervision $12/hr including fringes)	Battelle	2,500
Supplies	Hochheim	600
Tax/Insurance (2.7% of capital)	Battelle	15,200
Sub-Total Annual Operation Cost		$48,500

MAINTENANCE

Item	Source	Annual Cost
Labor ($10/hr including fringes)	Hochheim	$ 5,200
Supervision ($12/hr including fringes)	Hochheim	1,300
Administration ($10/hr including fringes)	Hochheim	400
Supplies	Hochheim	9,100
Labor for Major Repairs ($12/hr including fringes)	Hochheim	1,400
Sub-Total Annual Maintenance Cost		$17,400

ALLOWANCE FOR SALE OF COMPOST

Amount Produced	$7.65_3 m^3$/day	
Purchase Cost (Pick-up by purchaser)	$6/$m^3$	
Daily Allowance	$46.00	
Annual Allowance From Compost Sale		$16,800

SUMMARY

Annual Operation Cost	$48,500
Annual Maintenance Cost	17,400
Sub-Total O&M Cost	$65,900
Allowance for Compost Sale	16,800
TOTAL ANNUAL COST OF OPERATION	$49,100

TABLE 6. ANNUAL COSTS OF 250 CUBIC METER BAV SYSTEM

Item	Annual Cost
Amortization	
Equipment	$ 33,500
Structures	22,400
Operation and Maintenance	
(After benefit for compost sale)	49,100
TOTAL ANNUAL COST	$105,000

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APPENDIX A

THE TUNNEL REACTOR

BAV is currently developing a new within-vessel composting device, the "Tunnel-Reactor." It is planned that this device will replace the silo-type BAV composting vessel.

A pilot model of the Tunnel-Reactor is shown in Figure A-1. The major component is the long, rectangular steel reactor body or "tunnel." The pilot-unit tunnel is approximately 3.0 m long, 2.0 m high, and 1.0 m wide. Two full-scale sizes are anticipated: 19.0 m long, 3.5 m high, and 4.5 m wide; and 12.0 m long, 2.0 m high, and 2.5 m wide.

Loading is a batch operation, and is accomplished by an hydraulic ram, such as that on the left end of the tunnel in Figure A-1. When the ram is pulled back, a cavity forms between the ram and the wall of composting sludge.

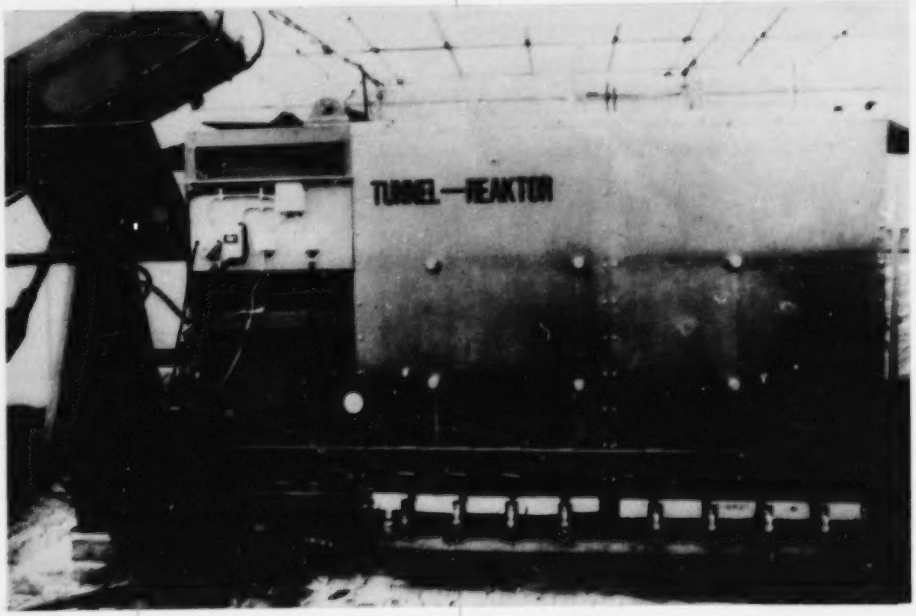

Figure A-1. The tunnel reactor.

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This cavity is then filled with a mixture of sludge cake, recycled compost, and sawdust. When the cavity is filled, the ram pushes the newly added mixture into the tunnel shaft. All of the composting sludge is, at the same time, pushed along in a plug-flow manner. Compost that is ready for curing is pushed out of the opposite end of the tunnel shaft by the action of the hydraulic ram. Loading does not take long, so most of the time the tunnel remains undisturbed.

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The Tunnel-Reactor is considered by BAV to be an improvement over the silo-type within-vessel composting unit. The flow of material through the unit should occur in a plug-flow mode, to avoid short circuiting. With the tunnel reactor, the addition of oxygen to various parts of the tunnel (or ages of composting material) can be controlled. A valved manifold (Figure 13) allows the operator to adjust the air flow to each portion of the tunnel. Another advantage of the tunnel reactor is the ease with which components can be repaired: there is no extraction mechanism, and the moving parts of the loading (hydraulic ram) system are located outside of the reactor, for easy access.

The Tunnel-Reactor is still being tested as a pilot unit. To date, it has been tested with municipal solid wastes and with horse and chicken manures. Testing with municipal wastewater treatment sludge is underway.

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APPENDIX B
BAV COMPOST MATURATION DATA SHEETS

Investigation of Composting Sample

Sample Number: 77/BAV/1/1 Test Date: 1 March 1977

Sampling Location:

Brilon-Messinghausen, after 14 days in Bioreactor and 4 weeks in curing pile.

Results of Analysis

1. Water Content: 68.52%
2. Organic Content: 84.69%
3. pH: 5.7

Physical Observations:

4. Fungus Growth: none
5. Structure: fine, crumbly
6. Odor: sour
7. Appearance: dark brown, moist

Plant Compatibility Test:

Cress Test

a. Sprouting: 98%
b. Growth: very good
c. Compatibility of Cress in this Sample: very good

Microscopic Examination:

8. Degree of Organic Substance Humification:
(Microscopic florescence test described by Dr. Pauli)

Additional Results:

- [ ] Strong florescence = very little decomposition
- [X] Medium strength florescence = medium decomposition
- [ ] Low strength florescence = extensive decomposition
- [ ] No florescence = very strong decomposition (up to 50%)

9. Principal Microorganisms in Composted Sludge:
(Investigation after 3 days of Aeration)

a. Bacteria: Actinomyces Farinosus (+), Micromonospora Species (+)
b. Fungus: Aspergillus Species (+)
c. Other Small Organisms: Nematodes (+), Milben (v)

(v) Scattered Incidence
\+ Lightly Dispersed
++ Numerous
+++ Densely Dispersed

10. Test Comments:

The sludge was well disintegrated. The woodchips indicate a small degree of digestion. The fungus colonization phase has begun. Isolated nematodes and milben were already present. The pH is somewhat low.

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Investigation of Composting Sample

Sample Number: 77/BAV/4/5

Test Date: 27 April 1977

Sampling Location:

Hilchenbach, 14 days in Bioreactor and 3 weeks in curing piles.

Results of Analysis

1. **Water Content:** 63.05%
2. **Organic Content:** 77.22%
3. **pH:** 7.2

Physical Observations:

4. Fungus Growth: medium, strength
5. Structure: fine to coarse, crumbly
6. Odor: light, sludge like
7. Appearance: dark brown

Plant Compatibility Test:

Cress Test

a. Sprouting: 80%

b. Growth: good

c. Compatibility of Cress in this Sample: extensive

Microscopic Examination:

8. **Degree of Organic Substance Humification:**
(Microscopic florescence test described by Dr. Pauli)

Additional Results:

- [ ] Strong florescence = very little decomposition
- [ ] Medium strength florescence = medium decomposition
- [X] Low strength florescence = extensive decomposition
- [ ] No florescence = very strong decomposition (up to 50%)

9. **Principal Microorganisms in Composted Sludge:**
(Investigation after 3 days of Aeration)

a. **Bacteria:** Actonomyces Farinosus (+) Bacterium Prodigiosum (++)

b. **Fungus:** Coprinus Cylindricus (++) Mucor Species (+) Penicillium Species (+)

c. **Other Small Organisms:** Nematodes (+) Milben (v)

(v) Scattered Incidence
+ Lightly Dispersed
++ Numerous
+++ Densely Dispersed

10. **Test Comments:**

This material has almost passed the optimal actinomyces phase, the disintergration made a good progress. The subsequent fungus colonization has established well; the early earth type small animals began to colonize.
The sample has not yet fully matured, however, it is extensively compatible for plant growth. There is a little supply of oxygen. (Thence, a light sludge odor).

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Investigation of Composting Sample

Sample Number: 76/BAV/11/2

Test Date: 22 November 1976

Sampling Location:

Delbruck, 3 weeks in Bioreactor and 3 weeks in curing piles

Results of Analysis

1. Water Content: 70.6%
2. Organic Content: 90.51%
3. pH: 6.0

Plant Compatibility Test:

Cress Test

a. Sprouting: 96%

b. Growth: very good

c. Compatibility of Cress in this Sample:

Physical Observations:

4. Fungus Growth: semi-strong
5. Structure: fine, crumbly
6. Odor: sour-like, strong
7. Appearance: dark brown

6-1/2"

Microscopic Examination:

8. Degree of Organic Substance Humification:
(Microscopic florescence test described by Dr. Pauli)

Additional Results:

☐ Strong florescence = very little decomposition

☒ Medium strength florescence = medium decomposition

☐ Low strength florescence = extensive decomposition

☐ No florescence = very strong decomposition (up to 50%)

9. Principal Microorganisms in Composted Sludge:
(Investigation after 3 days of Aeration)

a. Bacteria: Actinomyces Albus (+)
Actinomyces Farinosus (+)
Actinomyces Flavus (+)

b. Fungus: Micromonospora Elongata (+)
Trichoderma Lignorum (+++)

c. Other Small Organisms:
Milben (+)
Nematodes (v)

(v) Scattered Incidence
+ Lightly Dispersed
++ Numerous
+++ Densely Dispersed

10. Test Comments:

The material is at the end of the good actinomyces phase. Putrifaction may have progressed to the extent the C/N ratio may be normal. Fungi growth is occurring.

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Investigation of Composting Sample

Sample Number: 77/BAV/2/1 Test Date: 28 February 1977

Sampling Location:

Hilchenbach, after 5 weeks in curing pile

Results of Analysis

1. Water Content: 69.23%
2. Organic Content: 82.47%
3. pH: 7.3

Physical Observations:

4. Fungus Growth: none
5. Structure: fine to coarse, crumbly
6. Odor: little
7. Appearance: brown, moist

Plant Compatibility Test:

Cress Test

a. Sprouting: 98%
b. Growth: very good
c. Compatibility of Cress in this Sample: very good

Microscopic Examination:

8. Degree of Organic Substance Humification:
(Microscopic florescence test described by Dr. Pauli)

Additional Results:

[ ] Strong florescence = very little decomposition

[ ] Medium strength florescence = medium decomposition

[X] Low strength florescence = extensive decomposition

[ ] No florescence = very strong decomposition (up to 50%)

9. Principal Microorganisms in Composted Sludge:
(Investigation after 3 days of Aeration)

a. Bacteria: Actinomyces Globisporus Albus (+)
Actinomyces Farinosus (v)
b. Fungus: Cephalosporium Species (+)
Ascobolus Stercorarius (v)
c. Other Small Organisms: Nematodes (v)
Fliegenmaden (v)

(v) Scattered Incidence
+ Lightly Dispersed
++ Numerous
+++ Densely Dispersed

10. Test Comments:

The compost contains a high percentage of hard digestible wood pulp. The digestibility of the remaining organic material has well progressed. Because of high water content of the sample oxygen deficit has occurred? (Nematodes have indicated thus). The colonization of subsequent organisms (fungus) have fully established. Plant compatibility has been acknowledged.

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Investigation of Composting Sample

Sample Number: 76/BAV/6/1

Test Date: June 1976

Sampling Location:

Winterberg, after three weeks in curing piles

Results of Analysis

1. Water Content: 62.31%
2. Organic Content: 78.02%
3. pH: 5.6

Physical Observations:

4. Fungus Growth: semi-strong
5. Structure: 1/2" loose, crumbly
6. Odor: earthy
7. Appearance: turflike, brown

9-1/8"

Microscopic Examination:

8. Degree of Organic Substance Humification:
(Microscopic florescence test described by Dr. Pauli)

- [ ] Strong florescence = very little decomposition
- [x] Medium strength florescence = medium decomposition
- [ ] Low strength florescence = extensive decomposition
- [ ] No florescence = very strong decomposition (up to 50%)

Plant Compatibility Test:

Cress Test

a. Sprouting: 98%

b. Growth: Very Good

c. Compatibility of Cress in this Sample:

Additional Results:

9. Principal Microorganisms in Composted Sludge:
(Investigation after 3 days of Aeration)

a. Bacteria: Actinomyces Farinosus (+++)
Actinomyces Albus (++)

b. Fungus: Mucor Racemosus (+)

c. Other Small Organisms: Trichothecium Roseum (+)

(v) Scattered Incidence

\+ Lightly Dispersed
++ Numerous
+++ Densely Dispersed

10. Test Comments:

The material is not fully mature. Presence of a large number of Actinomyces Species guarantees a continued strong digestion. The composting is well established.

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Investigation of Composting Sample

Sample Number: 78/BAV/1/1

Test Date: 23 January 1978

Sampling Location:

Schefflenzal, 3 weeks in Bioreactor and 3 weeks in curing piles.

Results of Analysis

1. **Water Content:** 53.10%
2. **Organic Content:** 55.80%
3. **pH:** 7.9

Physical Observations:

4. Fungus Growth: little
5. Structure: fine, crumbly
6. Odor: earthlike-moist, very light, sludge odor
7. Appearance: earth-brown

Plant Compatibility Test:

Cress Test

a. Sprouting: 90%

b. Growth: good

c. Compatibility of Cress in this Sample: full

Microscopic Examination:

8. **Degree of Organic Substance Humification:**
(Microscopic florescence test described by Dr. Pauli)

Additional Results:

[ ] Strong florescence = very little decomposition

[ ] Medium strength florescence = medium decomposition

[X] Low strength florescence = extensive decomposition

[ ] No florescence = very strong decomposition (up to 50%)

9. **Principal Microorganisms in Composted Sludge:**
(Investigation after 3 days of Aeration)

a. **Bacteria:** Actinomyces Globisporus (v)

b. **Fungus:** Pencilliium Species (+++)
Trichoderma Lignorum (v)

c. **Other Small Organisms:** Nematodes (v)
Milben (v)

(v) Scattered Incidence
\+ Lightly Dispersed
++ Numerous
+++ Densely Dispersed

10. **Test Comments:**

The compost appears to be in the stage of earth fungus colonization (for example, penicillium). In relation to cress growth, this material was completely compatible. The pH could be maintained at a somewhat lower level. The water content is optimal.

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Investigation of Composting Sample

Sample Number: 77/BAV/3/1

Test Date: 1 March 1977

Sampling Location:

Lollar, after 8 days in curing piles

Results of Analysis

1. **Water Content:** 64.86%
2. **Organic Content:** 83.81%
3. **pH:** 6.6

Physical Observations:

4. Fungus Growth: very little to none
5. Structure: fine to coarse, crumbly
6. Odor: earthy, light sawdust smell
7. Appearance: 1/2" dark brown, moist

Plant Compatibility Test:

Cress Test

a. Sprouting: 96%

b. Growth: good

c. Compatibility of Cress in this Sample: adequate

Microscopic Examination:

8. **Degree of Organic Substance Humification:**
(Microscopic florescence test described by Dr. Pauli)

Additional Results:

[ ] Strong florescence = very little decomposition

[X] Medium strength florescence = medium decomposition

[ ] Low strength florescence = extensive decomposition

[ ] No florescence = very strong decomposition (up to 50%)

9. **Principal Microorganisms in Composted Sludge:**
(Investigation after 3 days of Aeration)

a. **Bacteria:** Actinomyces Globisporus (+) (v) Scattered Incidence

b. **Fungus:** Aspergillus Species (++) + Lightly Dispersed ++ Numerous +++ Densely Dispersed

c. **Other Small Organisms:** Nematodes (v)

10. **Test Comments:**

This material, in spite of not having sufficient digestion is suitable for plant growth. The slow digestion has occurred because of a high content of hard, digestible wood pulps. The actinomyces phase is extensively self-contained. Colonization by fungus has begun.

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